Discovery of Finely Structured Dynamic Solar Corona Observed in the Hi-C Telescope

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Abstract:

In the summer of 2012, the High-resolution Coronal Imager (Hi-C) flew aboard a NASA sounding rocket and collected the highest spatial resolution images ever obtained of the solar corona. One of the goals of the Hi-C flight was to characterize the substructure of the solar corona. We therefore examine how the intensity scales from AIA resolution to Hi-C resolution. For each low-resolution pixel, we calculate the standard deviation in the contributing high-resolution pixel intensities and compare that to the expected standard deviation calculated from the noise. If these numbers are approximately equal, the corona can be assumed to be smoothly varying, i.e. have no evidence of substructure in the Hi-C image to within Hi-C's ability to measure it given its throughput and readout noise. A standard deviation much larger than the noise value indicates the presence of substructure. We calculate these values for each low-resolution pixel for each frame of the Hi-C data. On average, 70% of the pixels in each Hi-C image show no evidence of substructure. The locations where substructure is prevalent is in the moss regions and in regions of sheared magnetic field. We also find that the level of substructure varies significantly over the roughly 160 s of the Hi-C data analyzed here. This result indicates that the finely structured corona is concentrated in regions of heating and is highly time dependent.

The Hi-C Data:

- The Hi-C instrument flew on a NASA sounding rocket on July 11, 2012.
- The target of the Hi-C observations was Active Region 11520.
- Hi-C obtained 30 full frame, full resolution images with 2 s exposure time and 5.5 s cadence.
- The Hi-C data was dark-current subtracted and flatfielded to remove the shadow of the mesh from the images. The data were corrected for atmospheric absorption. The Hi-C data were also corrected for dust on the detector.
- The 30 Hi-C images were co-aligned. Additionally, they were aligned to the AIA data.

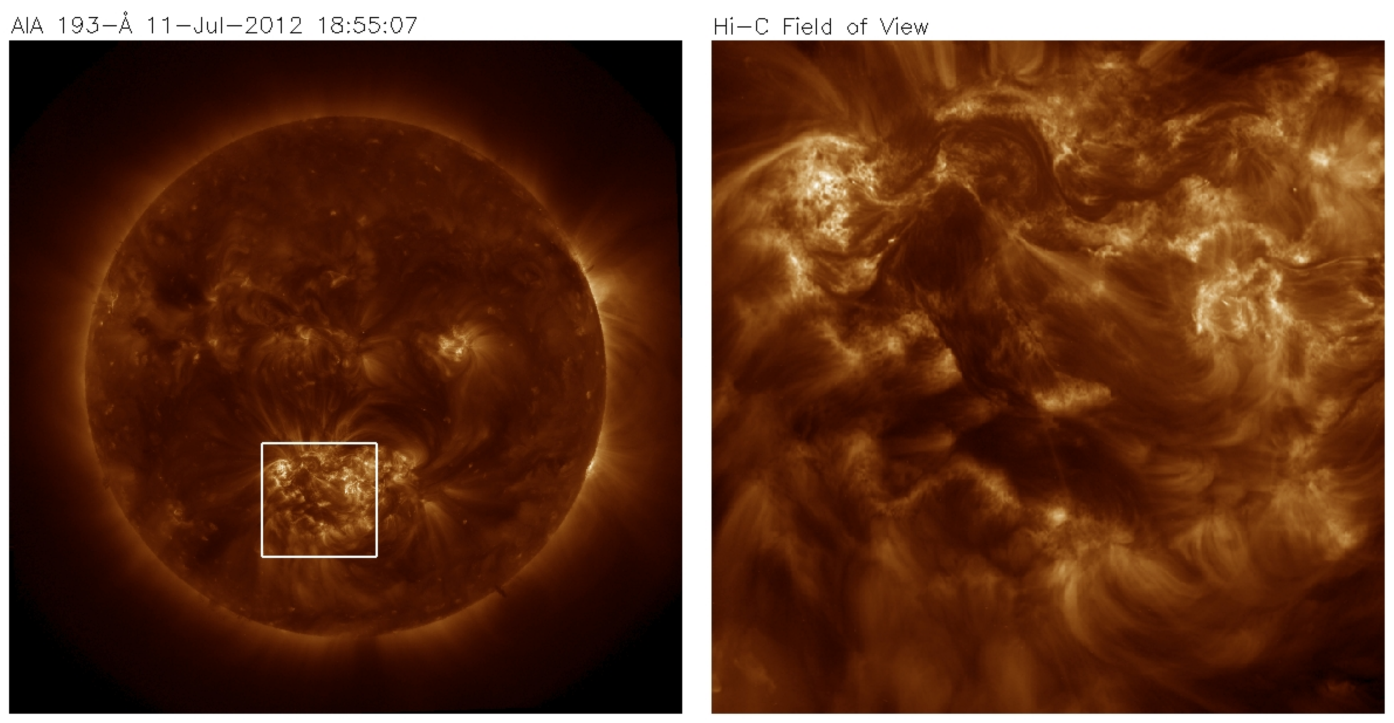

Figure 1: The full disk AIA image (right) and Hi-C field of view (left).

Hypothesis:

- If the corona is smoothly varying over large (> 1.2") scales, then the Hi-C intensities in every 12x12 pixel region should be Gaussian distribution with a width equal to the noise (photon and readout).
- If the corona is structured at smaller spatial scales, then the distributions of intensities should be broader than can be explained by noise.

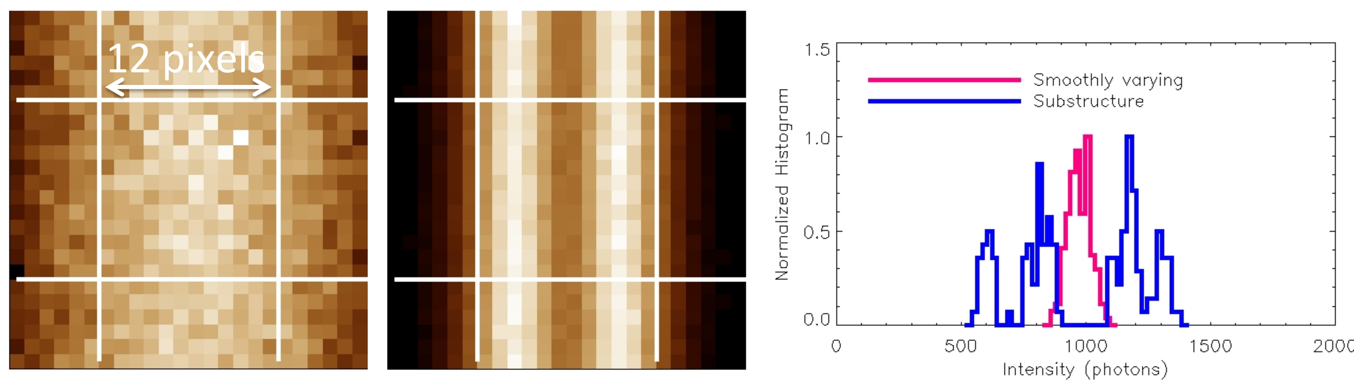

Figure 2: Examples of smoothly varying and substructured corona.

Low-resolution Data:

It is difficult to compare directly the AIA to Hi-C data. The throughput of the Hi-C telescope is 5.3 times the throughput of the AIA telescope. Additionally, the shape of the passband is slightly different. The AIA images are taken at a lower cadence and different times. Hence, we generate low-resolution, "AIA-like" from the Hi-C data by smoothing to 1.2" and binning the Hi-C data to 0.6" pixels.

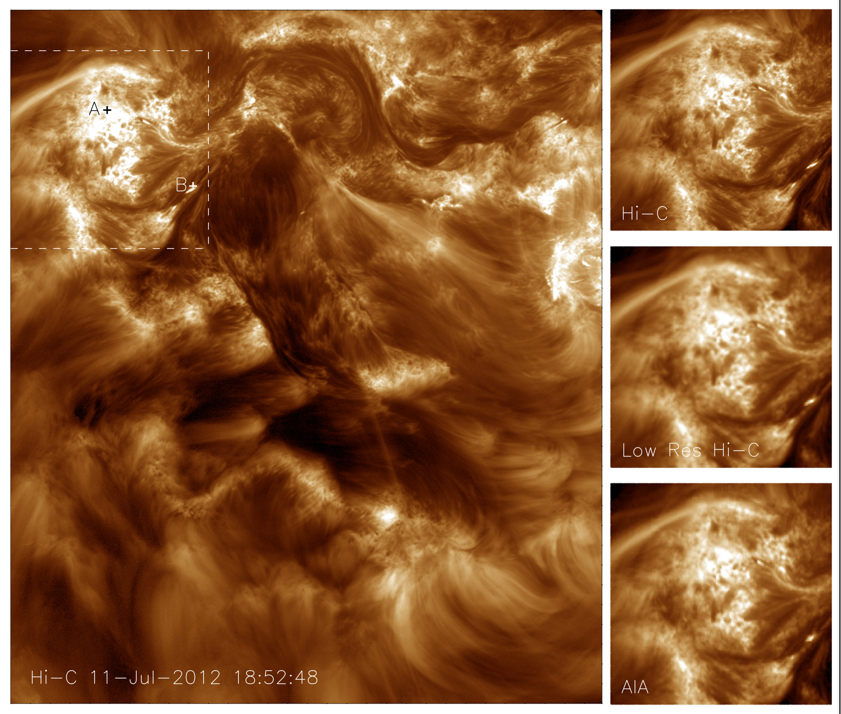

Figure 3: The Hi-C field of view considered in this study is shown on the left. Two example pixels are marked with A and B. The cutout region, shown with a dashed line, is shown on the right panel in Hi-C, low-resolution Hi-C and AIA.

Examples:

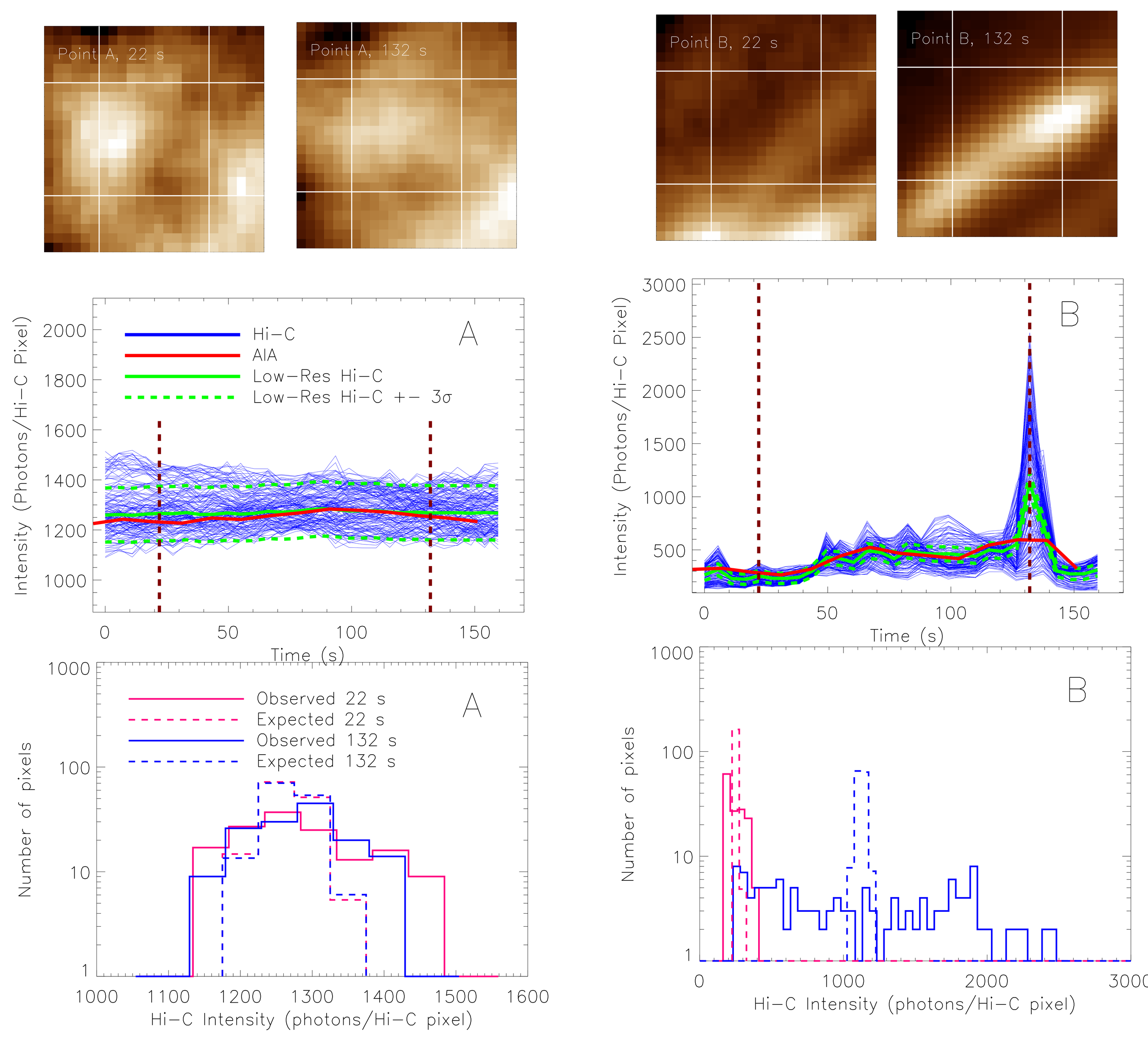

Figure 4: See description below.

- The region around the two pixels shown in Figure 3 are shown in the upper panels at two different times. Pixel A is in the moss region and Pixel B is a loop. The macropixels (12x12 Hi-C pixels) are highlighted.
- The middle panels show the lightcurves of all 12x12 Hi-C pixels (blue) that contribute to a single macropixel. The low-resolution Hi-C data (green) and the AIA data (red) are also shown. The dashed green lines show the low-resolution intensity +- 3σ.
- In the lower panels, we show the histograms of the 12x12 Hi-C intensities at two different times (solid red and blue) and compare to the expected histograms based on the noise (dashed).
- At both times, for both points, we measure the standard deviation in the 144 Hi-C pixel intensities and compare to the expected standard deviation based on the noise. The results are given in the table below.

Point	Time	St Dev	Noise	St Dev/ Noise
A	22 s	84.6	36.1	2.3
A	132 s	66.8	36.1	1.9
B	22 s	60.5	17.0	3.6
B	132 s	654.6	34.1	19.2

Table 1: Example measured standard deviations, noise, and ratios.

- **If the ratio of the measured standard deviation to the expected noise is > 1, the distribution of Hi-C intensities cannot be explained by noise and hence, there must be substructure.**

Results:

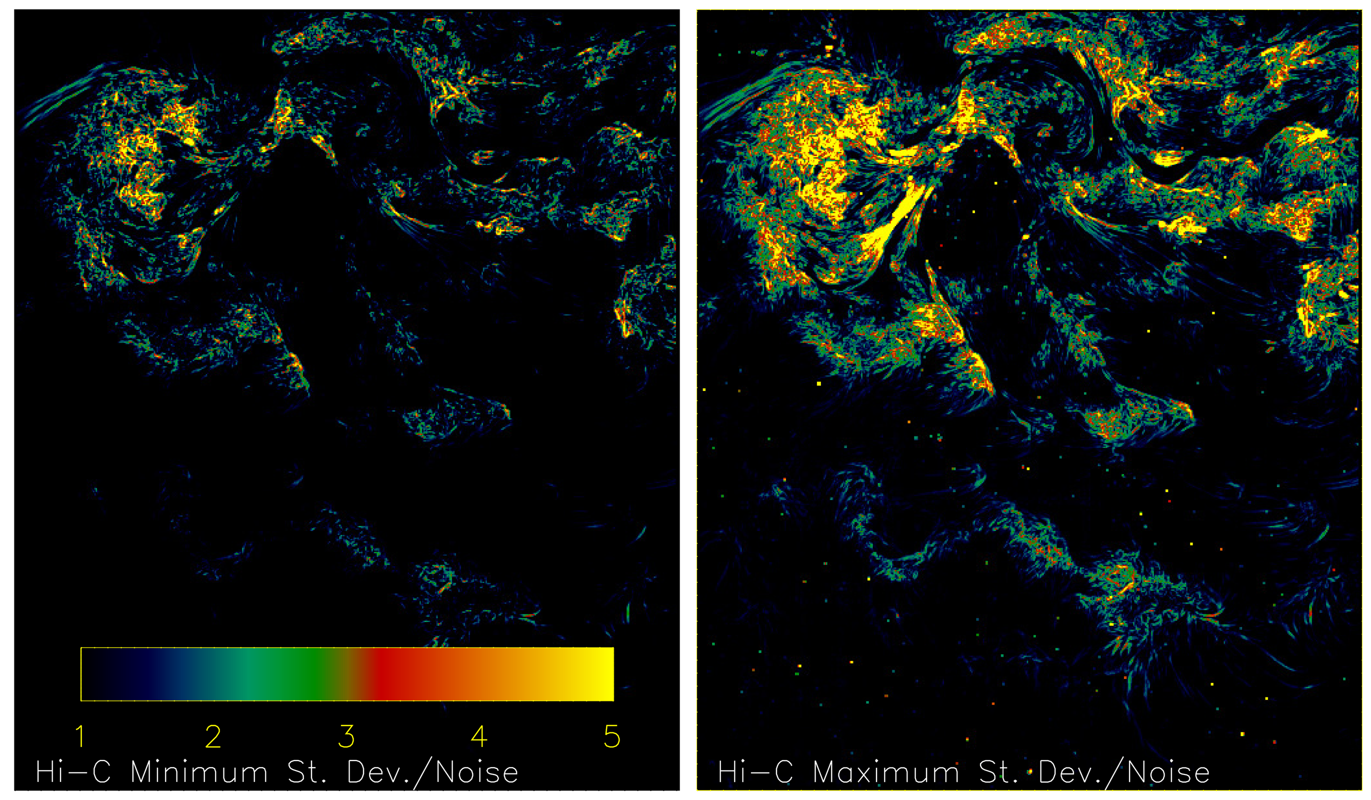

Figure 5: See description below.

- For each 12x12 Hi-C pixel subregion and at each time, we calculate the standard deviation in the intensities and compare that to the noise. Figure 5 shows the minimum and maximum ratio of measured standard deviation to calculated noise.
- Regions that are black in the figure indicate where the distribution of intensities can be explained by noise. Regions that are red and yellow indicate regions of significant substructure.
- Most substructure is located in moss and regions of strong magnetic shear.
- This ratio can change significantly over time at a single pixel location. Of the pixels that have a minimum ratio greater than 1, 52% of the ratios increase by a factor of 50% and 13% of the ratios increase by a factor of 2.

Comparison with AIA:

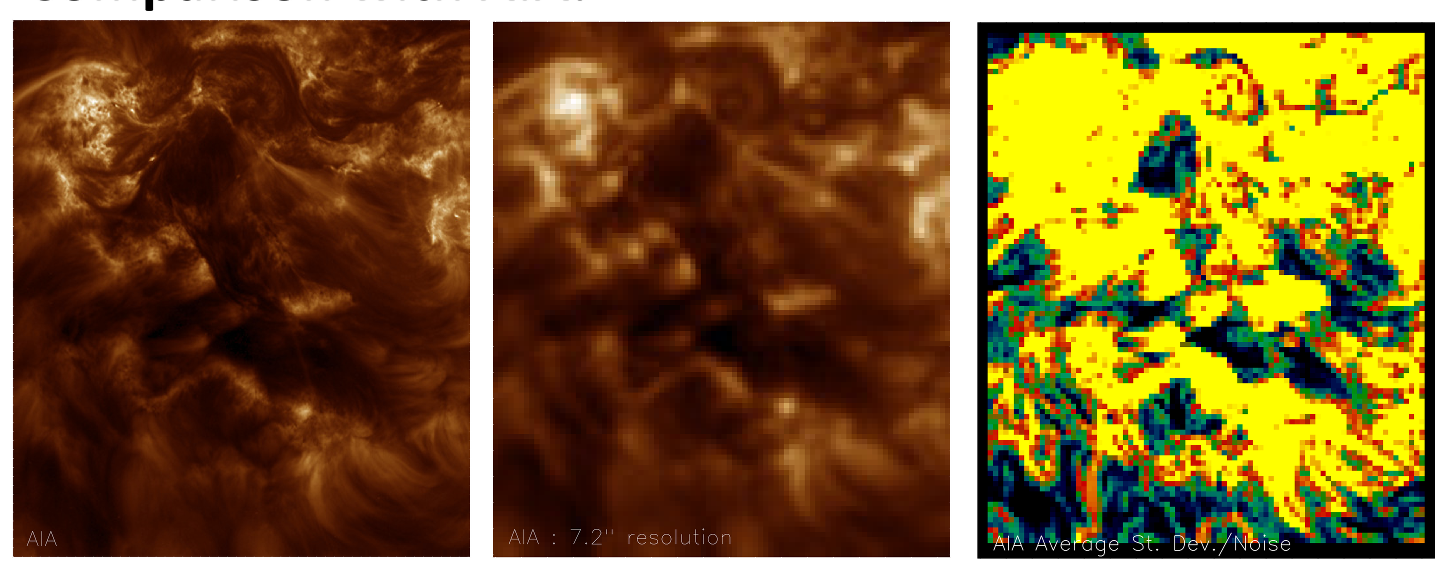

Figure 6: See description below.

- We degrade the AIA resolution to 7.2" (the same jump in resolution as Hi-C to AIA) and perform identical analysis.
- The results, shown in Figure 6, were dramatically different. More than 50% of the pixels had ratios > 5. The ratios in each pixel were more stable. Only 3.5% of the ratios increased by a factor of 50%. Comparison of the percentage of pixels in different ratio ranges is given in Table 2.

	Hi-C Minimum St. Dev/Noise	Hi-C Maximum St. Dev/Noise	AIA Minimum St. Dev/Noise	AIA Maximum St. Dev/Noise
<1	81.3	53.7	3.9	0.6
1-3	17.2	40.3	32.0	28.2
3-5	1.3	4.7	22.6	23.7
>5	0.2	1.3	41.4	47.4

Table 2: Percentage of pixels with various ratios for Hi-C and AIA.

Conclusions:

Hi-C reveals the presence of dynamic substructure in active region moss and regions of strong magnetic shear.